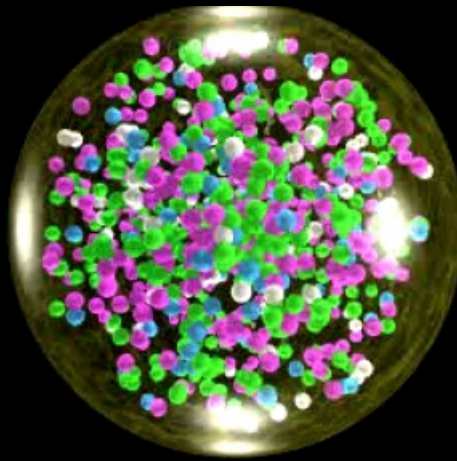


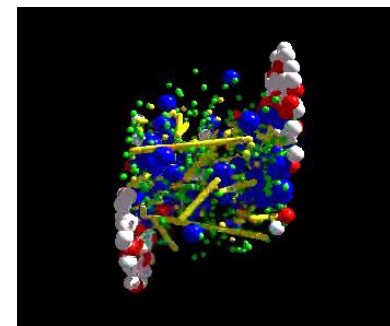
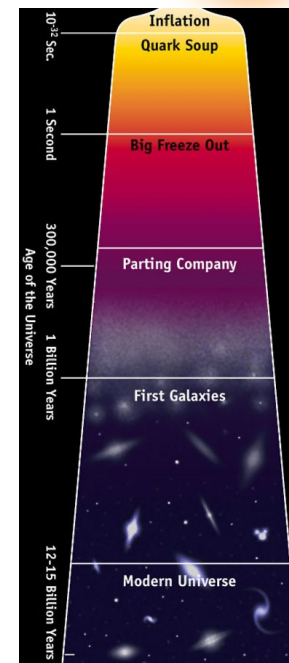
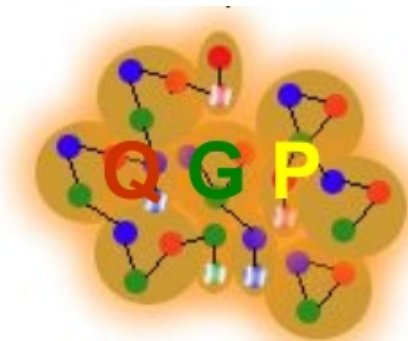
*The little bang: understanding  
the quark gluon plasma*



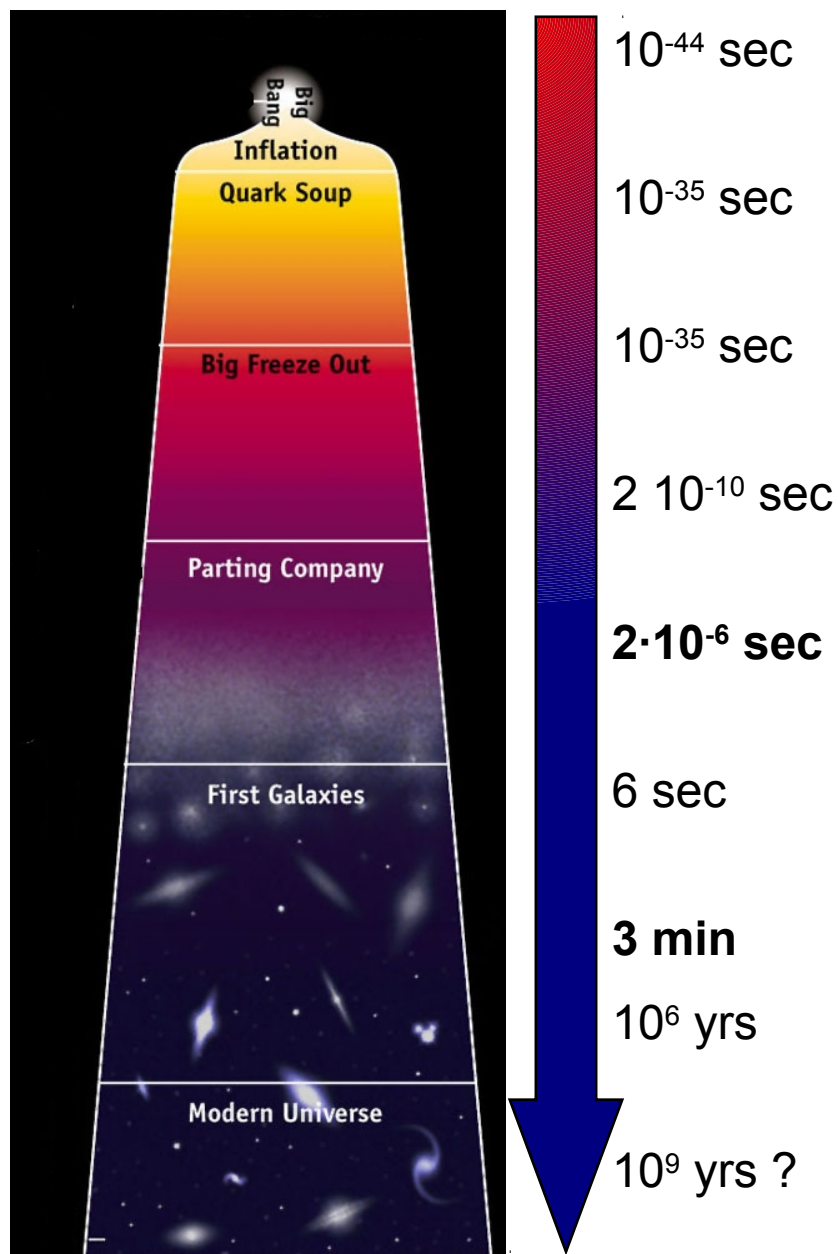
*Christine Nattrass  
University of Tennessee at Knoxville*

# Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



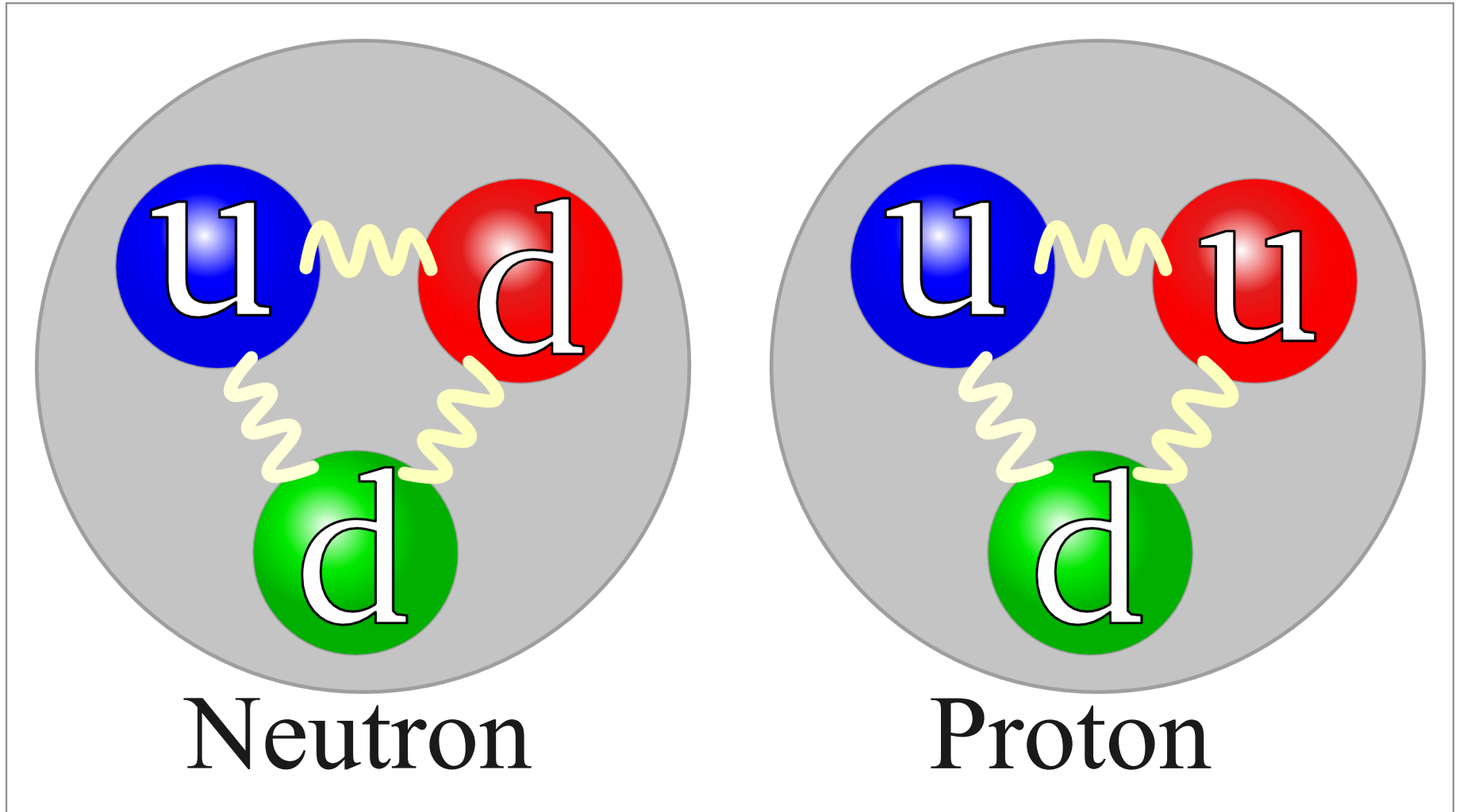
# Evolution of the Universe



**The universe gets cooler!**

Reheating matter?  
Need temperatures  
around  $1.5 \cdot 10^{12}$  K  
 $\sim 10^6$  times hotter than  
the core of the sun

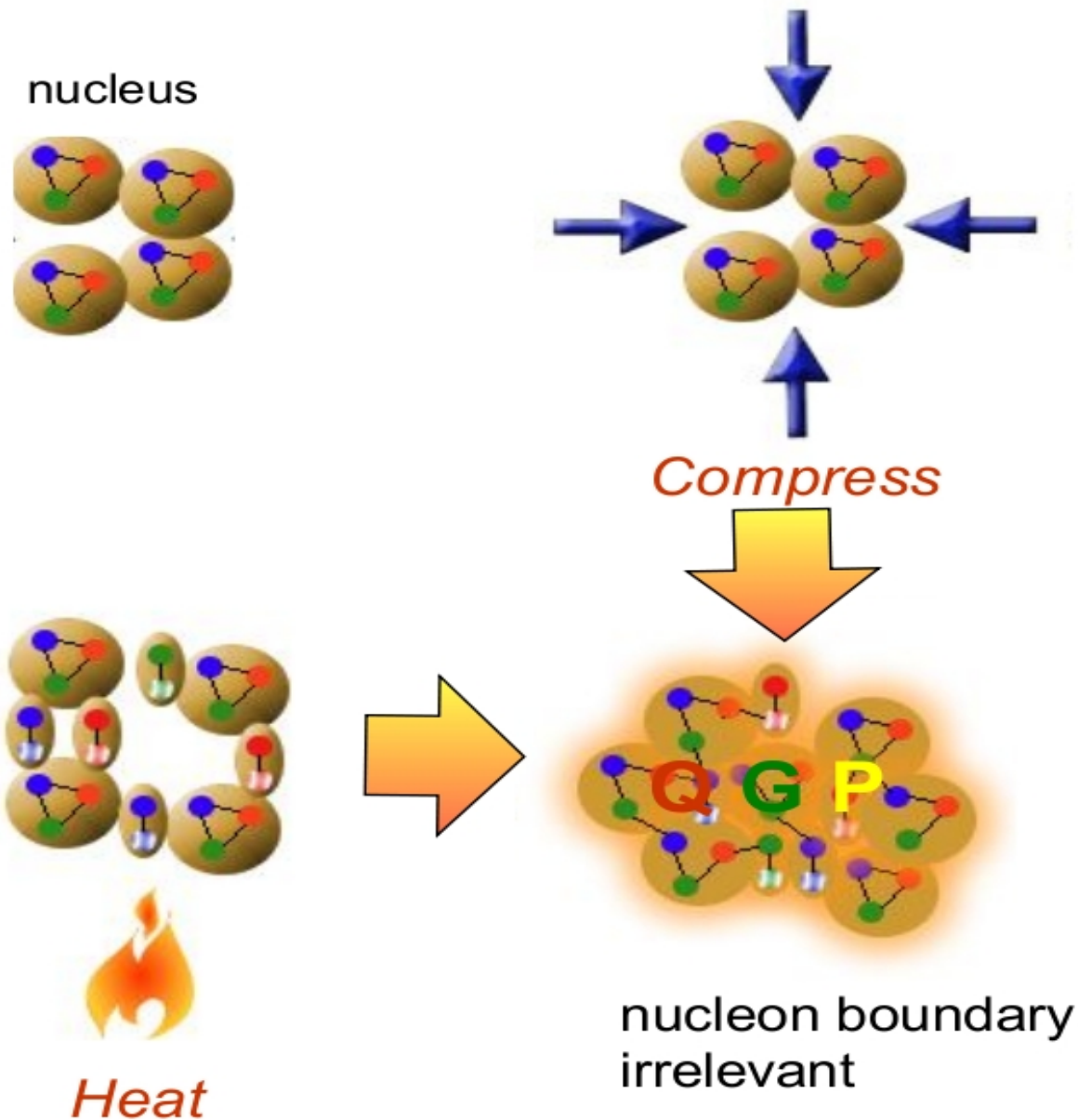
# Nucleons – the proton and neutron



[http://en.wikipedia.org/wiki/Image:Quark\\_structure\\_neutron.svg](http://en.wikipedia.org/wiki/Image:Quark_structure_neutron.svg)

[http://en.wikipedia.org/wiki/Image:Quark\\_structure\\_proton.svg](http://en.wikipedia.org/wiki/Image:Quark_structure_proton.svg)

# How can we see “free” quarks?

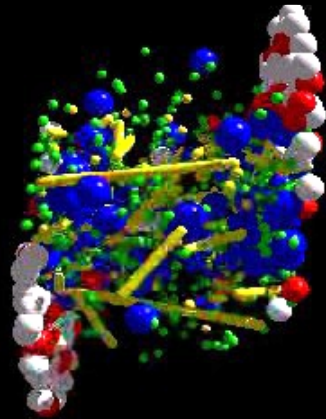


# Making a QGP in the laboratory

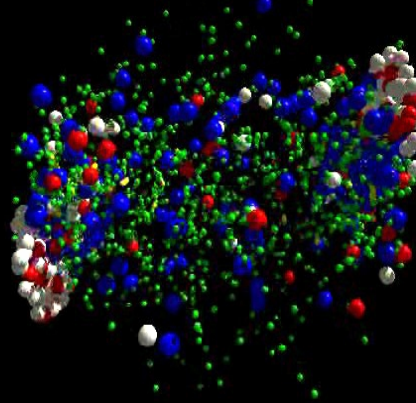
Relativistic pancakes

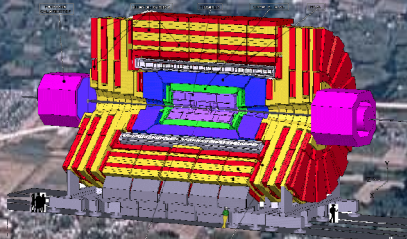


Quark soup



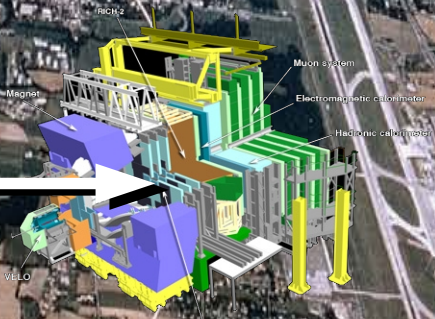
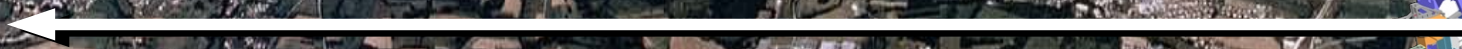
Explosive hadron soda





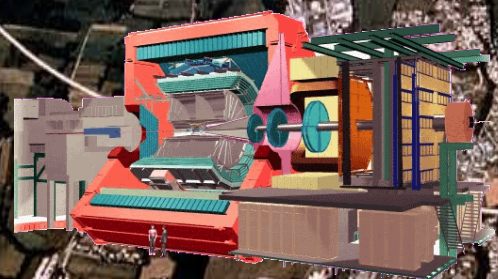
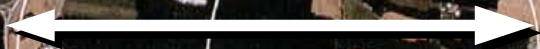
**CMS**

**5.3 miles**

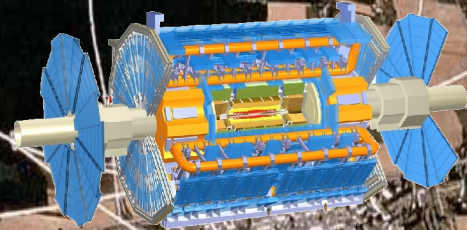


**LHCb**

**1.4 miles**

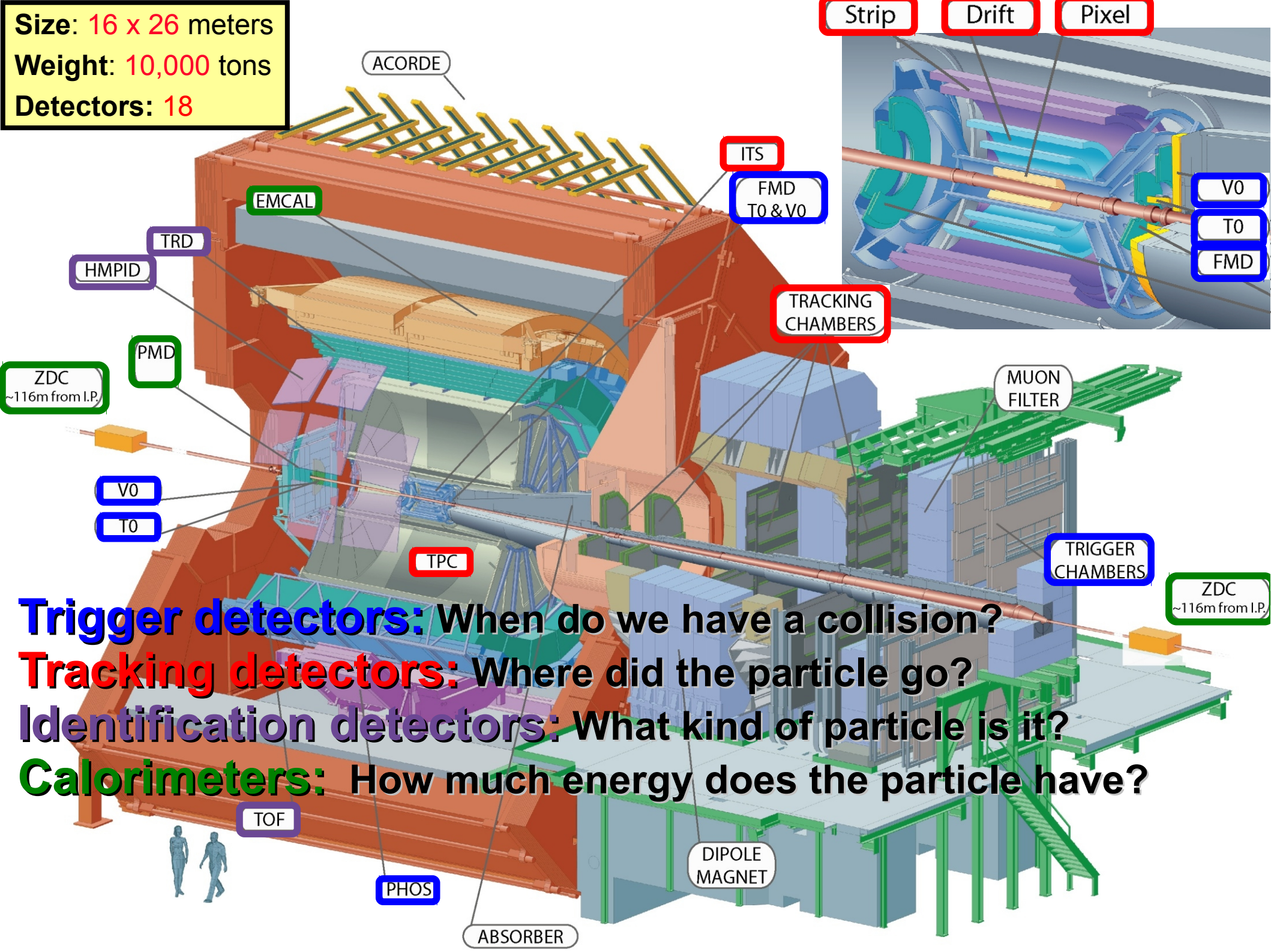


**ALICE**

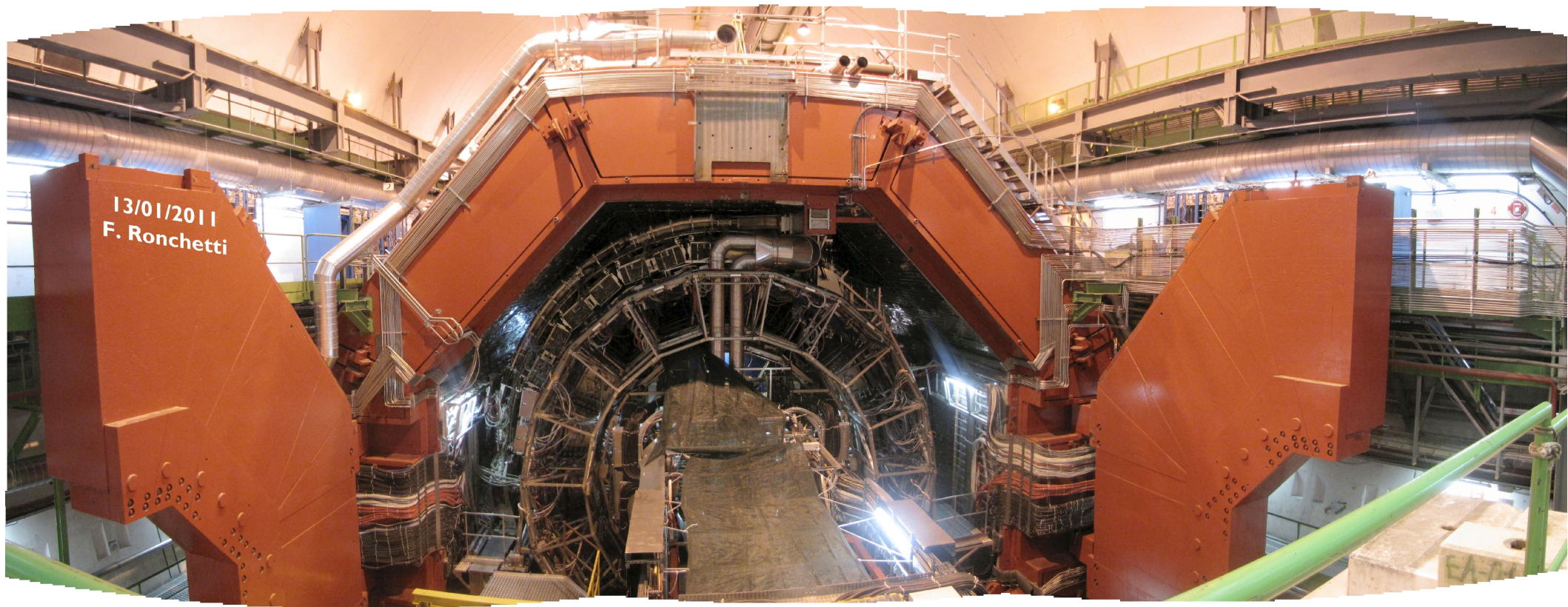


**ATLAS**  
**LHCf**

**Size:** 16 x 26 meters  
**Weight:** 10,000 tons  
**Detectors:** 18

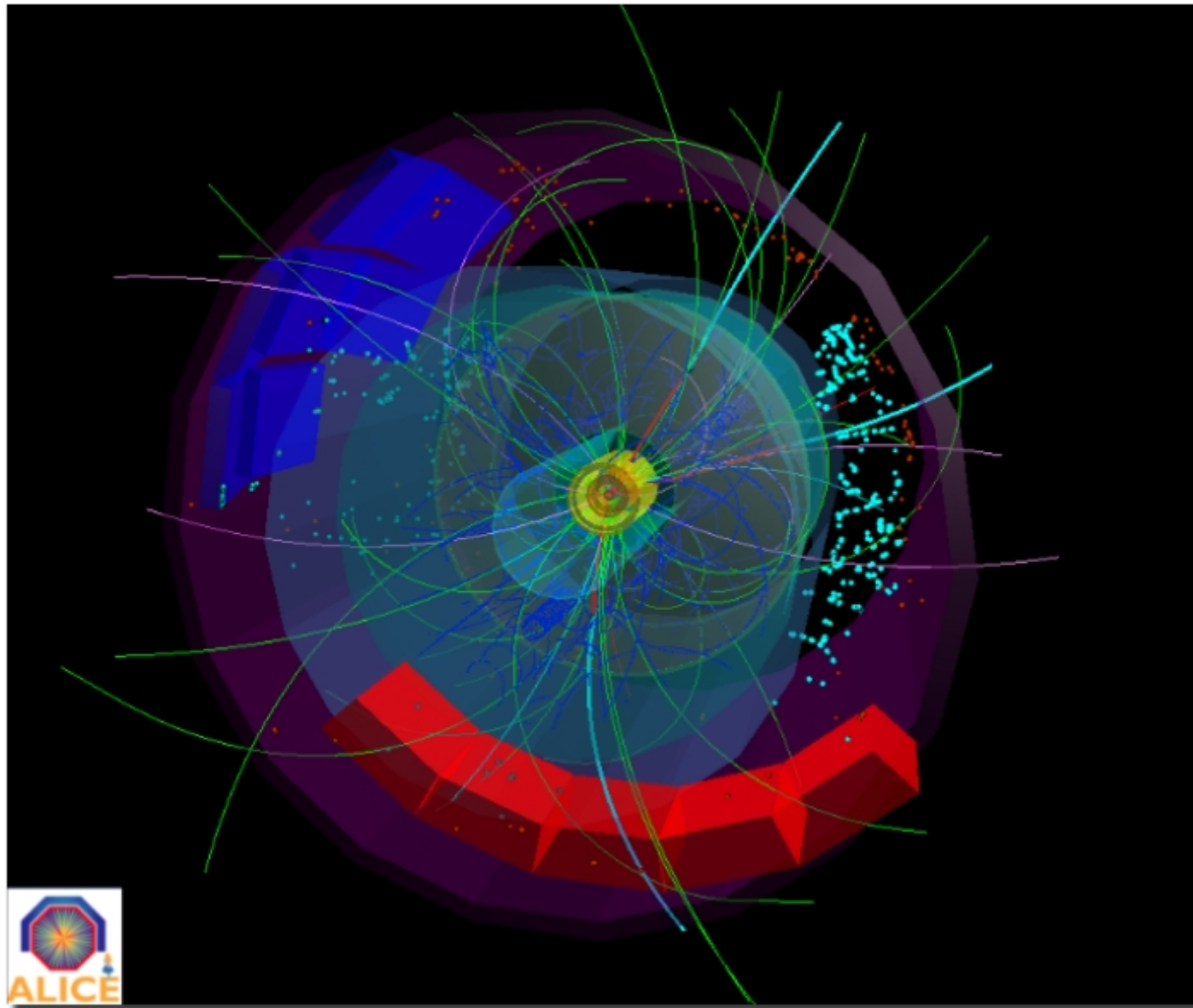


**Trigger detectors:** When do we have a collision?  
**Tracking detectors:** Where did the particle go?  
**Identification detectors:** What kind of particle is it?  
**Calorimeters:** How much energy does the particle have?

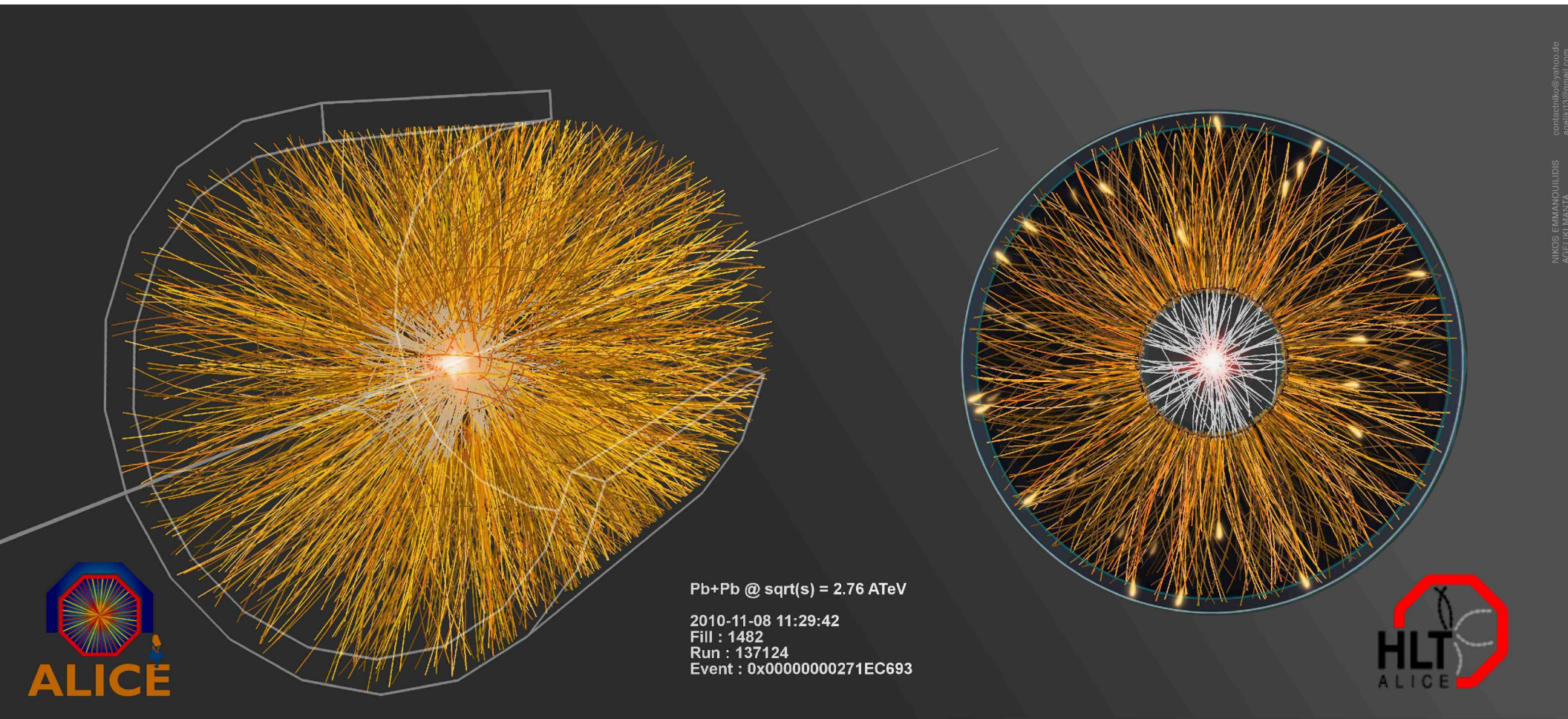




# p+p collisions



# Pb+Pb collisions



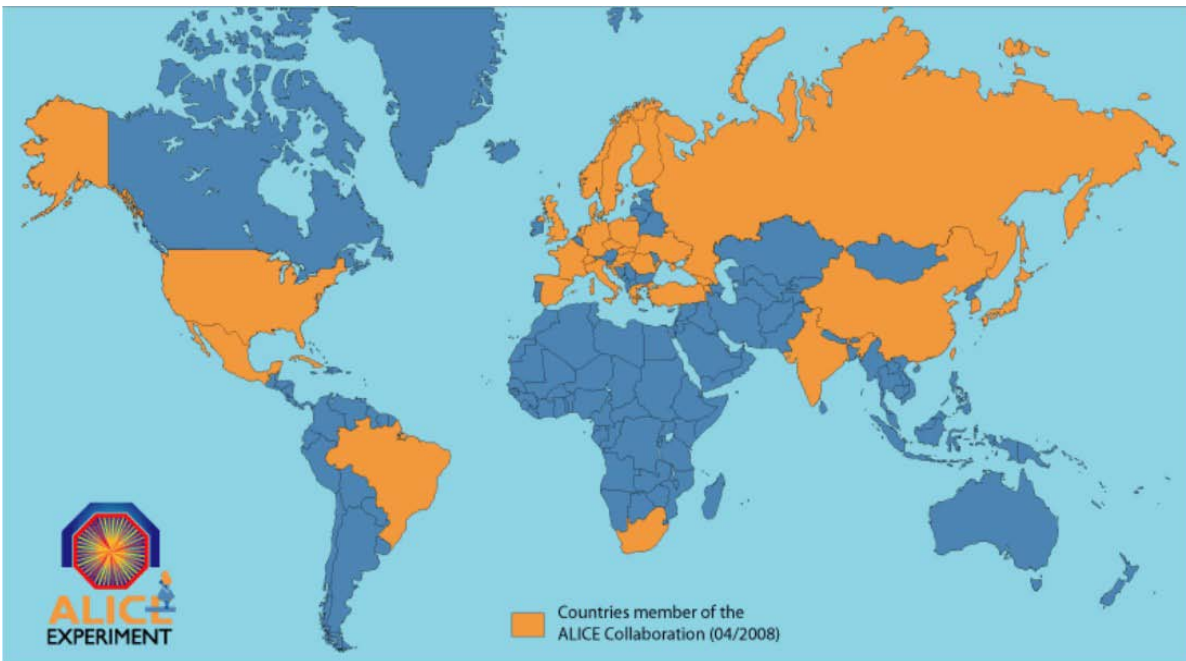
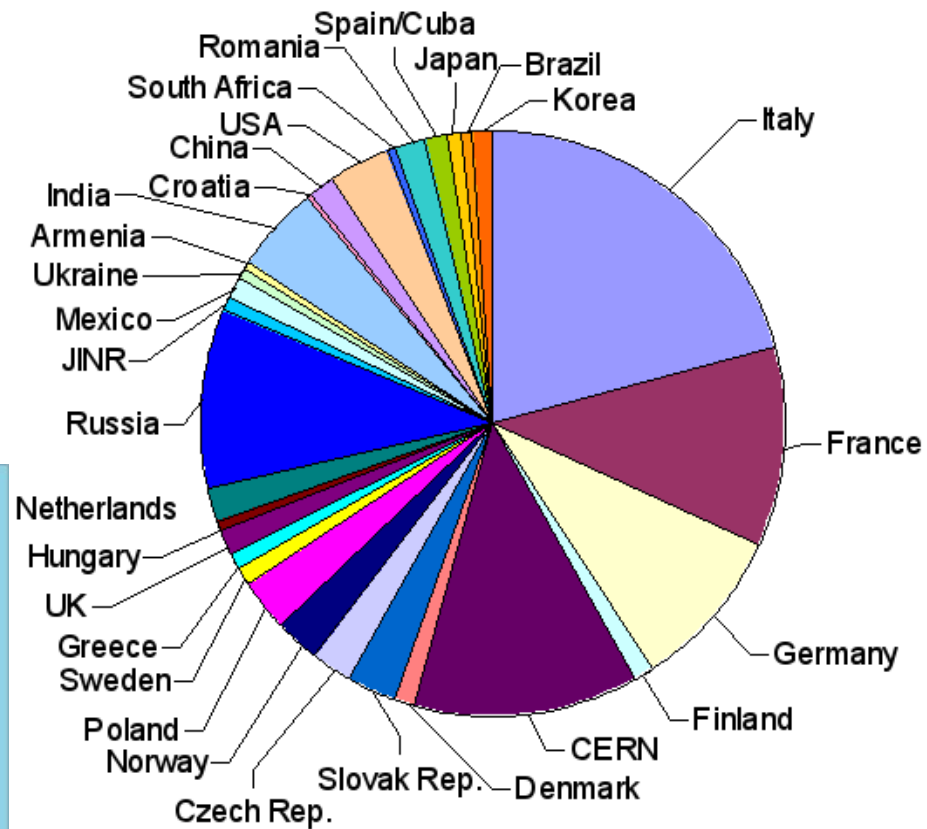
# The ALICE Collaboration

~1000 Members  
63% from CERN  
member states

~30 Countries

~100 Institutes

~\$150 million Capital cost  
(+magnet)



# Scales

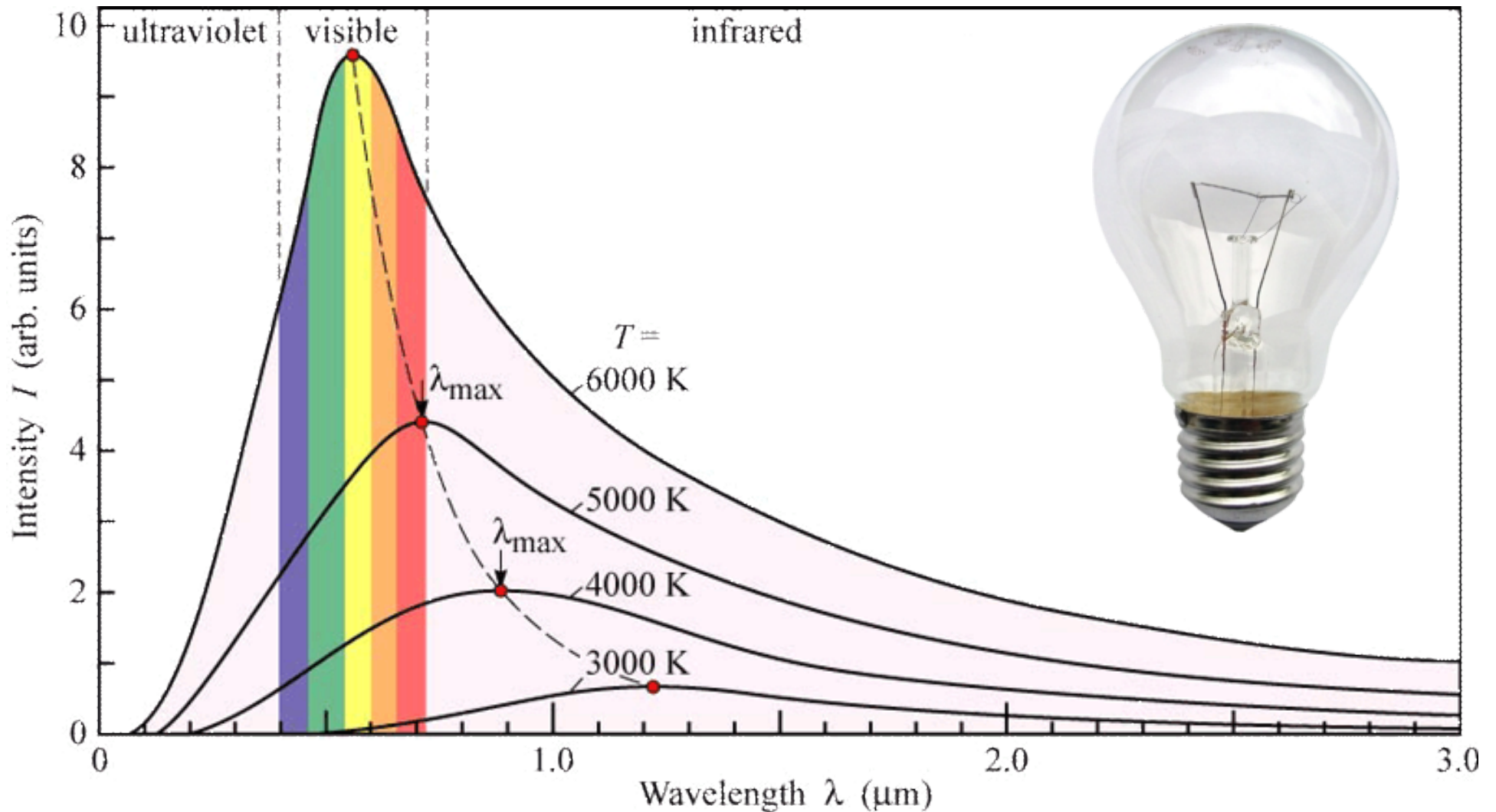
- Time:  $\sim 10^{-23}$  seconds
  - 1 minute for us  $\sim 1,000,000$  lifetimes of the universe for QGP
- Energy: 1 TeV  $\sim 10$  trillionths ( $10^{-11}$ ) of a Calorie
  - About the amount of energy if two mosquitoes collide
  - About 1 trillionth of a candy bar
- Energy density:  $\sim 6-8 \text{ GeV}/\text{fm}^3$ 
  - $10^{35}$  times that of a candy bar ( $\sim$ trillion trillion trillion candy bars)
  - About the energy density if you packed the energy that could be released from a million kg of fuel for a nuclear power plant into a cube with each side the width of a hair
- Temperature:  $\sim 1.5$  billion Kelvin
  - A million times hotter than the core of the sun

# Scales

- Number of particles:  $\sim 2000-3000$ 
  - Same number as in  $1 \mu\text{m}^3 = 1/16 \text{ in}^3$  of air
- Size of QGP:  $1 \text{ fm}^3 = 10^{-45} \text{ m}^3$ 
  - If this room were the size of the solar system, the QGP could fit in  $1 \text{ cm}^3$
- Data volume: PB  $\sim 1,000,000$  GB
- Data rates:  $\sim 1$  PB/month written to disk, a few GB/second

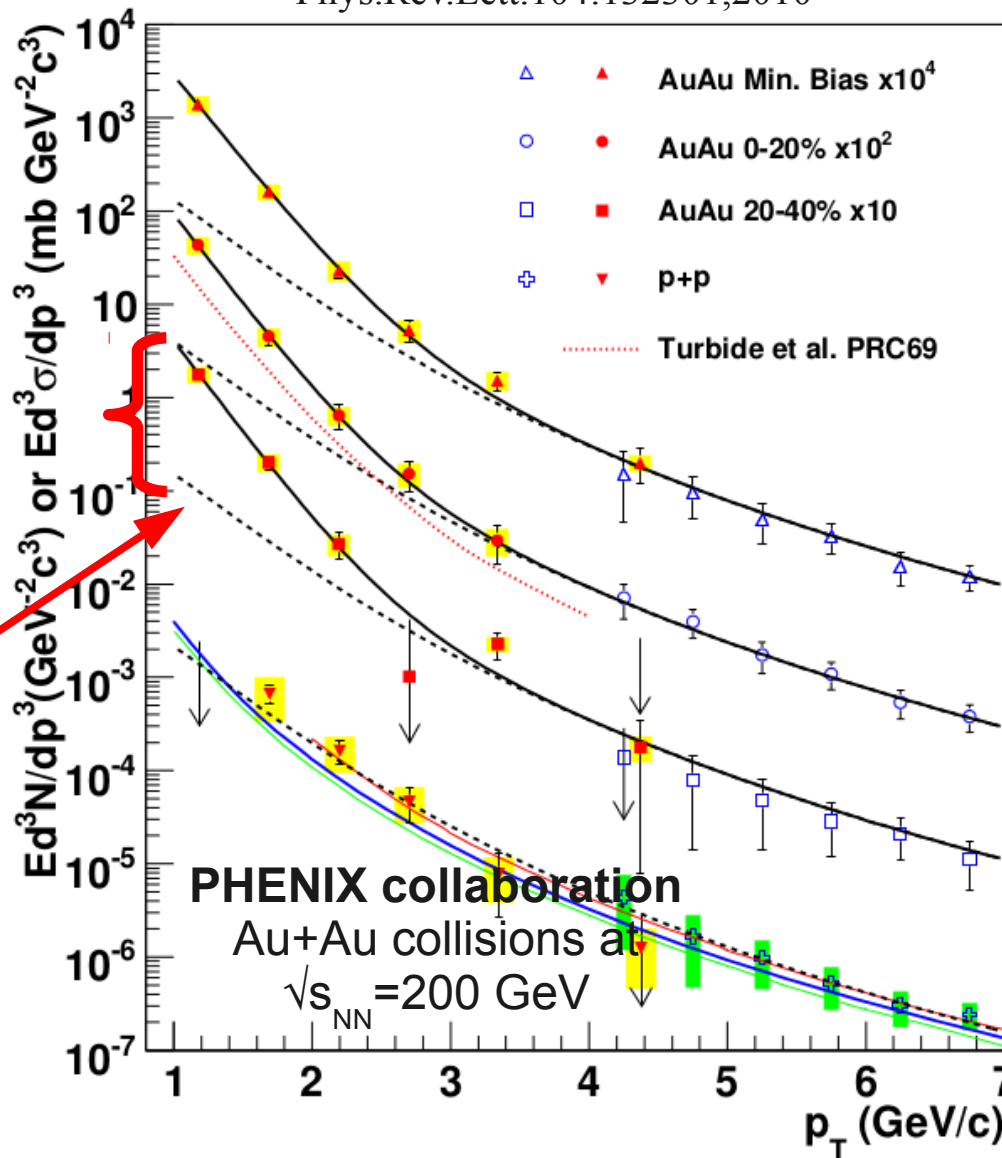
# Measuring temperature

# Thermal photons



# Thermal photons

Phys.Rev.Lett.104:132301,2010



Thermal photons

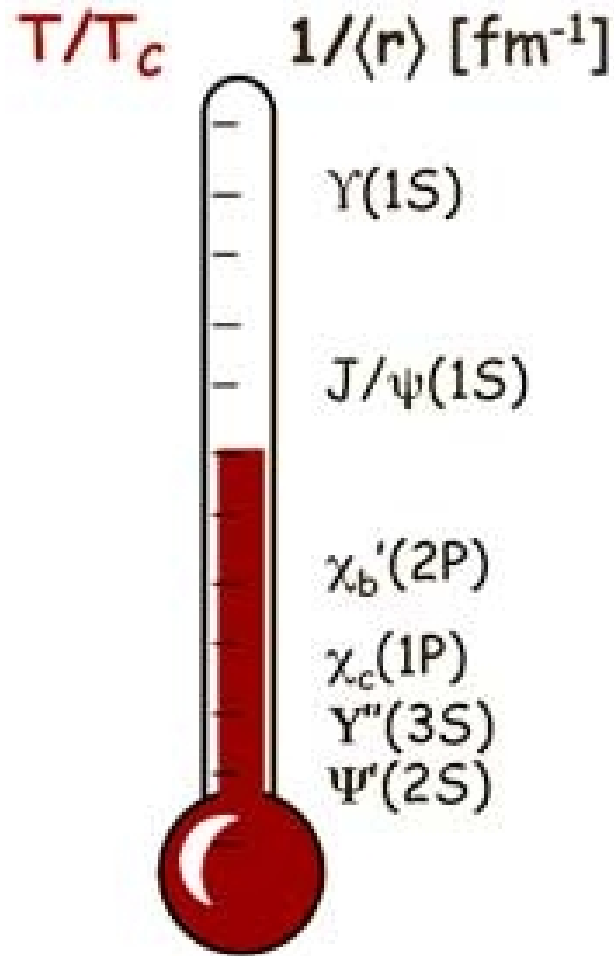
Inverse slope:  
 $T = 221 \pm 19$  (stat)  $\pm 19$  (syst) MeV

Consistent with models with  
 $T = 300-600$  MeV

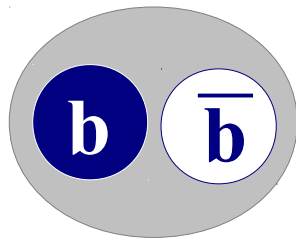
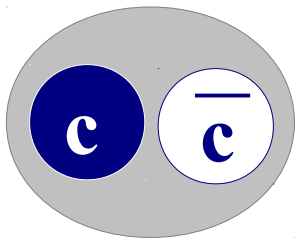
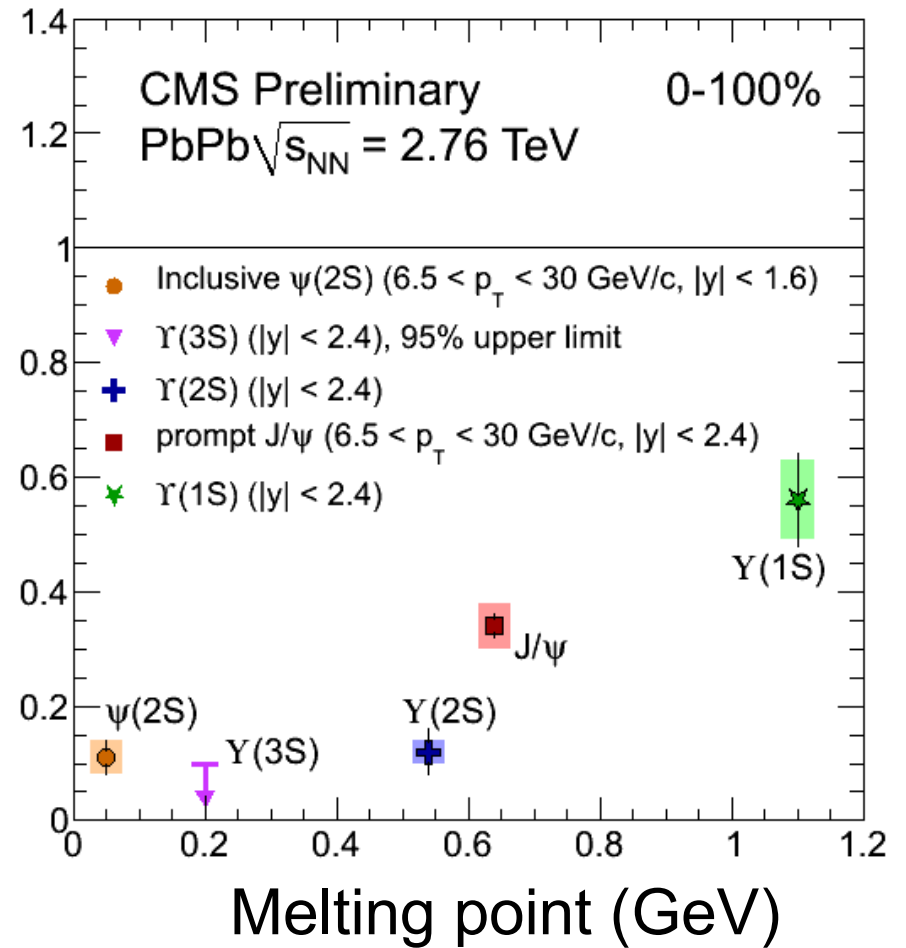
$T_c \sim 170$  MeV

Other processes

# Quarkonium-thermometer



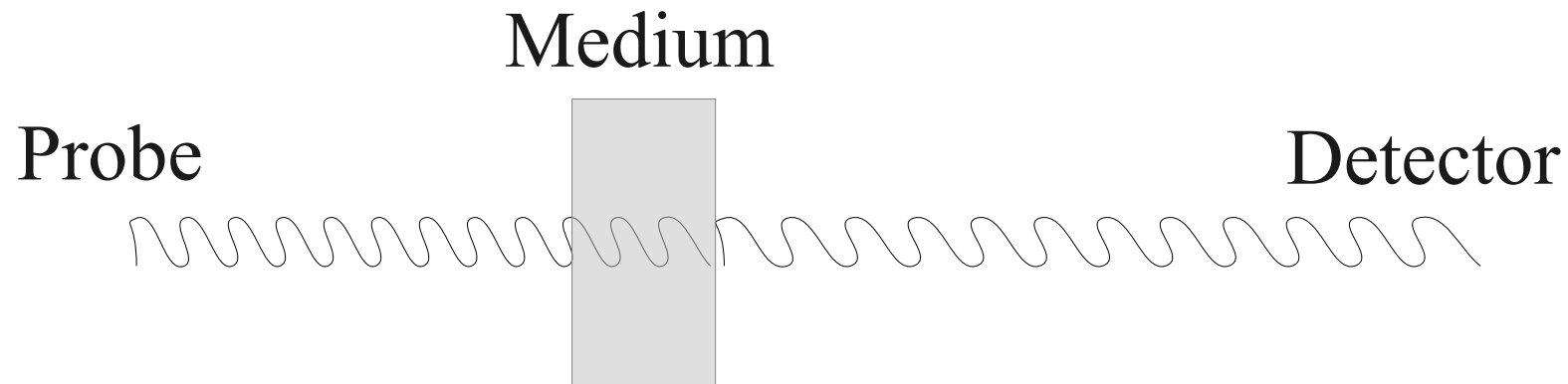
Number of particles seen/number of particles created



CMS-PAS HIN-12-014, HIN-12-007

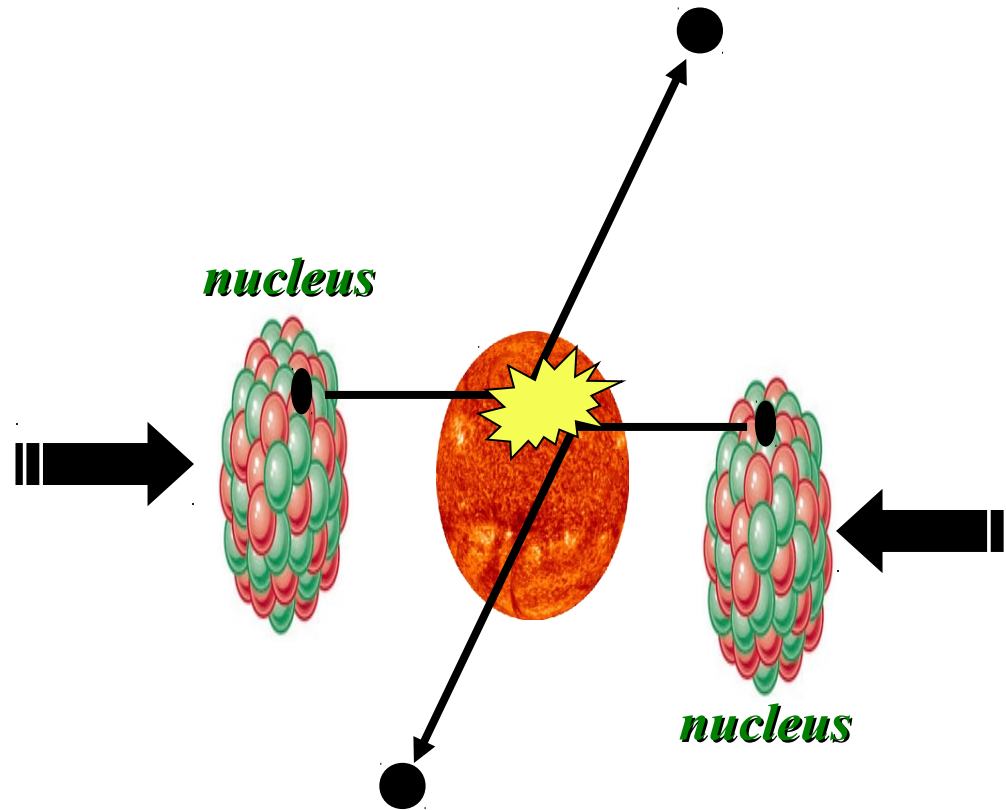
# Imaging the Quark Gluon Plasma

# Probing the Quark Gluon Plasma



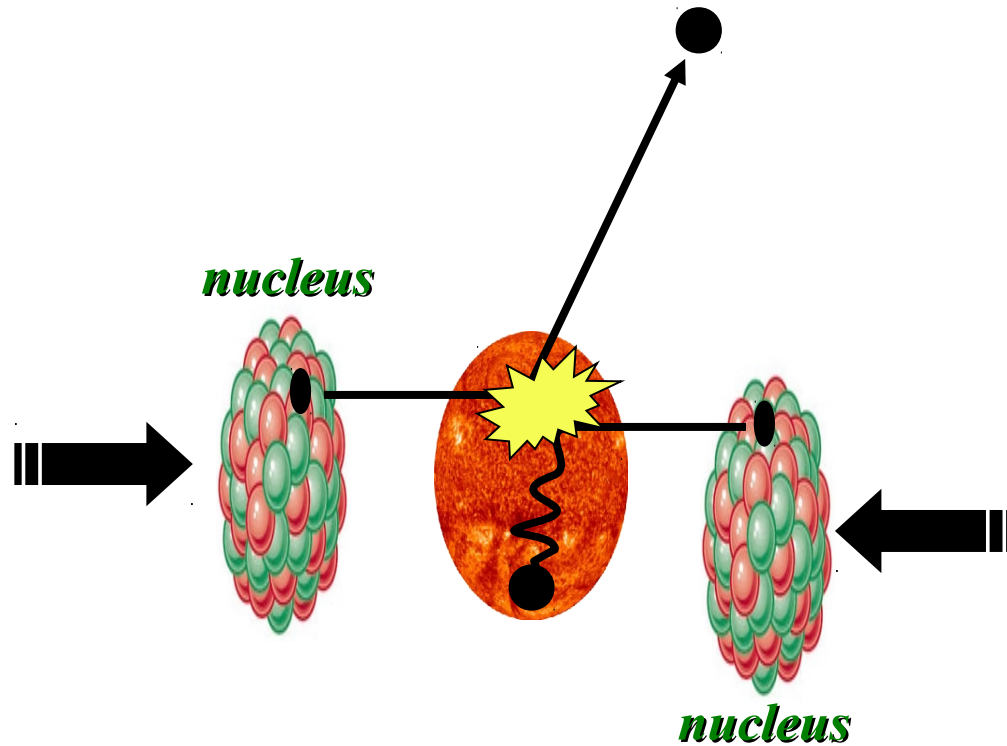
Want a probe which traveled through the collision  
QGP is very short-lived ( $\sim 1-10$  fm/c)  $\rightarrow$   
cannot use an external probe

# Probes of the Quark Gluon Plasma



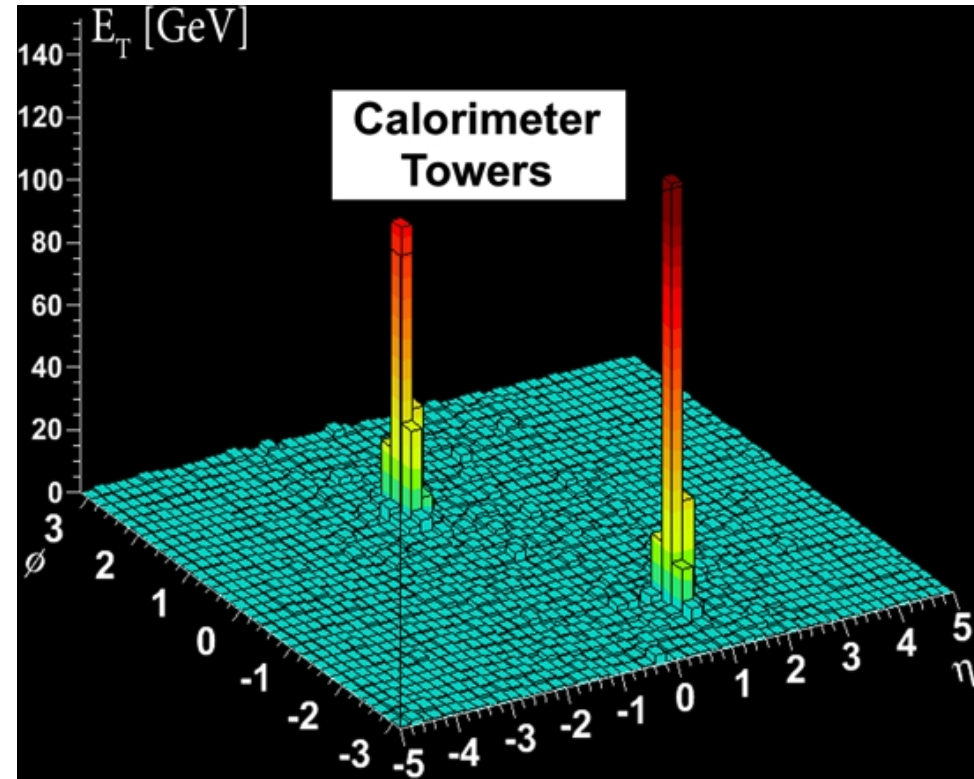
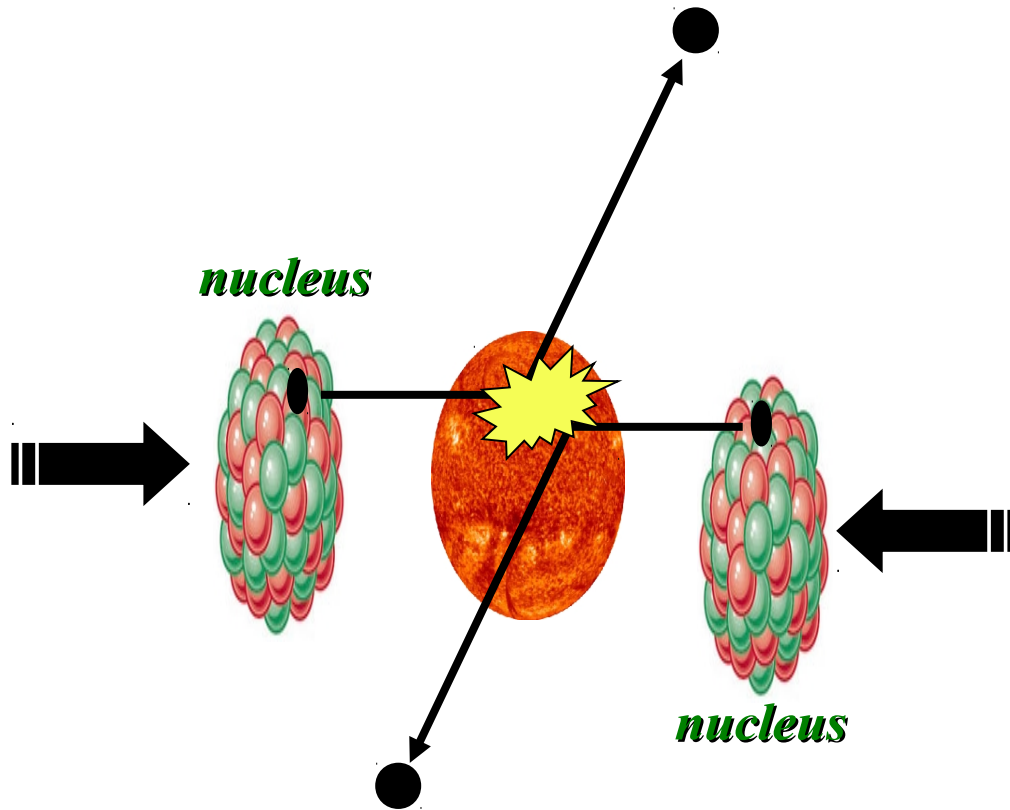
Want a probe which traveled through the medium  
QGP is short lived  $\rightarrow$  need a probe created in the collision

# Probes of the Quark Gluon Plasma



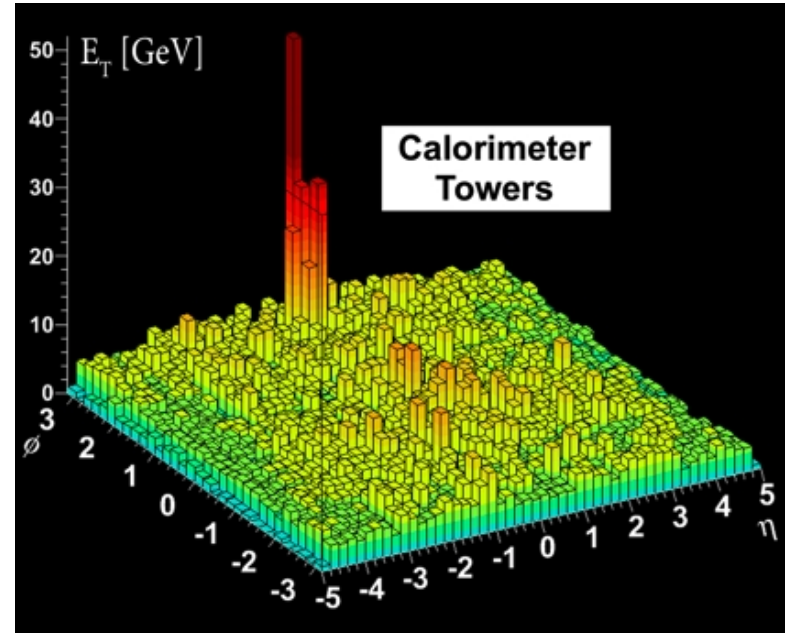
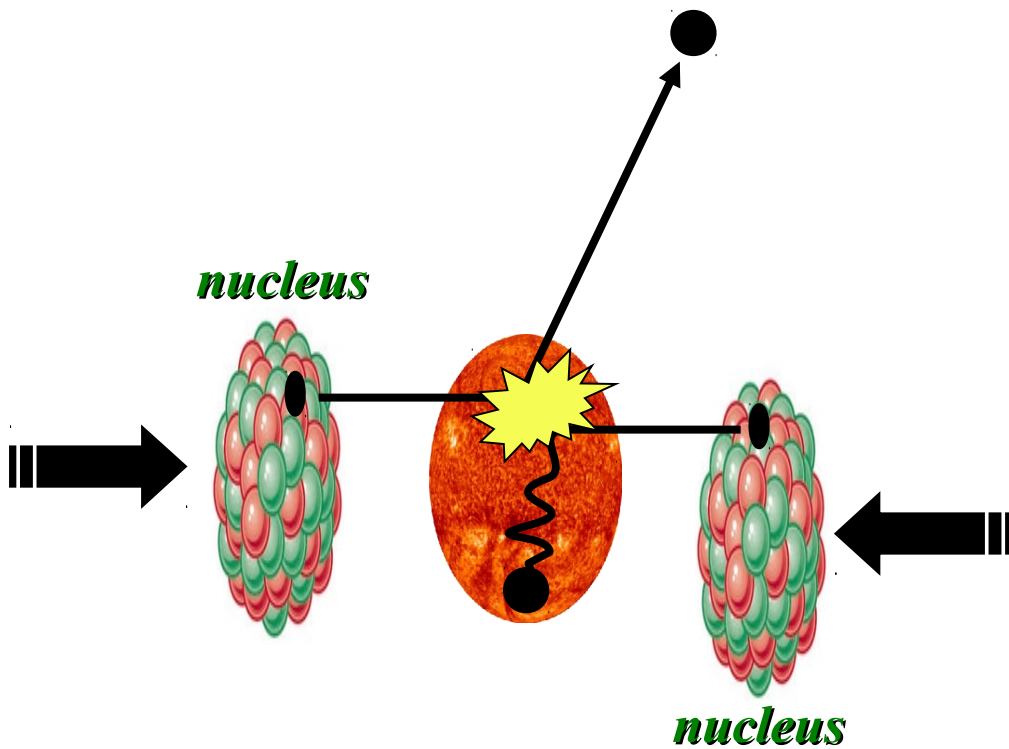
Want a probe which traveled through the medium  
QGP is short lived  $\rightarrow$  need a probe created in the collision  
We expect the medium to be dense  $\rightarrow$  absorb/modify probe

# Jets



- Quarks and gluons are confined – we don't see them outside of mesons and baryons
- Instead we see a cone of particles around the outgoing quark or gluon
- Looking at jets analogous to spectroscopy

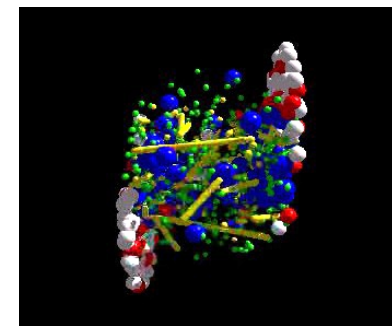
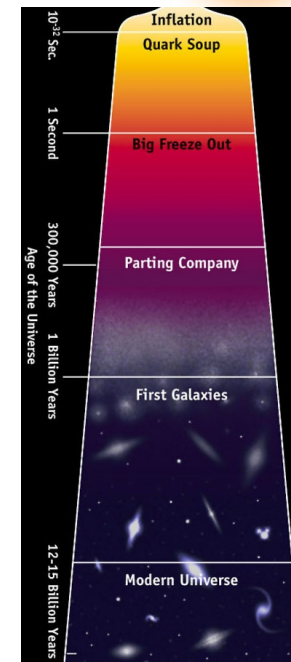
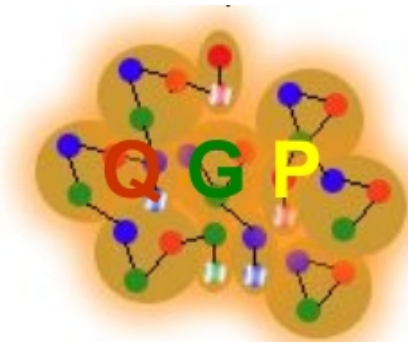
# Quenched jets



- One of the jets is absorbed by the medium
- The quark or gluon has equilibrated with the medium
- [Phys. Rev. Lett. 105, 252303 \(2010\)](#)

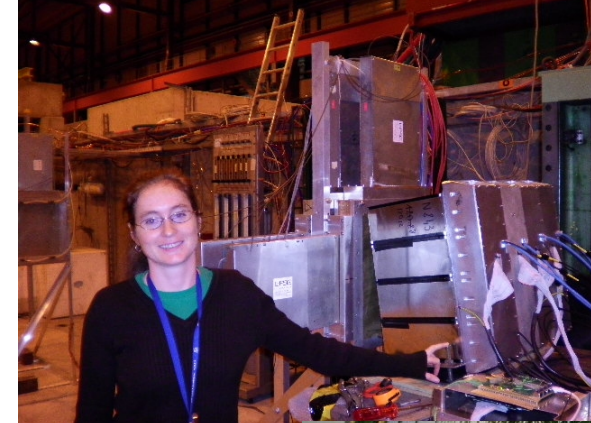
# Take home messages

- If we get nuclear matter dense enough, we make a new phase of matter
- This quark gluon plasma is similar to what was present in the early universe
- We can produce a QGP in high energy heavy ion collisions



# What I spend my time doing

- Programming (c++) - analyzing data
- Writing and giving talks – 3 research talks, 1 seminar, 2 posters, 1 software tutorial, and lots of talks (>30) at internal meetings in 2010
- Hardware work: assembling & testing the detector
- Working with graduate students
- Outreach: blogging for ALICE, giving tours of PHENIX to the public...
- Writing papers and conference proceedings
- Reviewing the work of my collaborators
- Running our journal club
- Reading papers
- Taking shifts – including being on call 24/7











Christine Nattrass(UTK





# Resources

- US LHC [blog](#) and Facebook [page](#)
- Experiments
  - Relativistic Heavy Ion Collider: [STAR](#) [PHENIX](#)
  - Large Hadron Collider: [ALICE](#) [ATLAS](#) [CMS](#) [LHCb](#)  
[TOTEM](#)
- Event displays and pretty pictures from [ALICE](#)
- Really cool [ATLAS](#) event animation
- Links to articles in the press on [PHENIX](#)
- Scientific American [article](#)